9. ACOUSTIC RESULTS OF 707-320B AIRPLANES WITH ACOUSTICALLY TREATED NACELLES

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SUMMARY

This paper summarizes the acoustic results from the test program carried out on the acoustically treated nacelles developed by The Boeing Company under Contract NAS 1-7129. The test airplane was a Boeing 707-320B powered by JT3D-7 engines. The effective perceived noise level reductions achieved, as demonstrated by the flight tests, were 15.5 EPNdB on landing approach, 3 EPNdB during take-off, 5.5 EPNdB during take-off with power cutback, and 3.5 EPNdB in sideline noise.

INTRODUCTION

Presentations at the NASA technical conference in October 1968 (ref. 1) summarized the development of acoustic lining technology applicable to engine nacelle treatment for reducing fan generated noise. This technology has been applied to treat four JT3D-7 engine nacelles. These four flightworthy nacelles were first tested on an engine test stand to ensure that adequate noise reduction was achieved, and then were evaluated by flight testing.

Static ground test results were evaluated in terms of the perceived noise level (PNL) scale. All flight test results were evaluated in terms of effective perceived noise level (EPNL) to account for time and tone correction factors. The principal results of the acoustic tests are presented in this paper.

ABBREVIATIONS

PNL	perceived noise level
PNLM	maximum perceived noise level
PNdB	unit of PNL
EPNL	effective perceived noise level
EPNdB	unit of EPNL
SPL	sound pressure level, dB re 2×10^{-4} microbar

TEST ENGINE CONFIGURATIONS

The two nacelles tested on the basic JT3D-7 engine are shown in figure 1. The existing short duct JT3D-7 nacelle was used as the untreated base line. The acoustically treated test nacelle has an extended inlet incorporating lining materials in the outside wall, two concentric rings, and the centerbody. The fan exhaust duct of the treated nacelle is extended to be almost coplanar with the primary nozzle and is acoustically lined in the areas shown.

ACOUSTIC TEST PROGRAM

The acoustic test program consisted of both ground tests and flight tests. During ground testing, noise measurements were made for the existing and treated nacelles to determine the effectiveness of the acoustic treatment. The flyover noise levels of the airplanes with the existing and treated nacelles were estimated from these test-stand results prior to the flight tests.

During flight testing, noise measurements were made under the airplane flight path during landing approach, take-off, take-off with power cutback, and 400-foot-altitude level flyovers at various power settings. Noise levels were also recorded 1500 feet to the side of the flight path during take-offs.

ACOUSTIC GROUND TEST RANGE

The acoustic ground test range is shown schematically in figure 2. Noise measurements were made in the acoustic far field by two microphone arrays centered on the engine test stand. Measurements in the vertical plane were taken primarily to evaluate the ground effects on noise recordings in the horizontal plane, which contained the principal microphone array. The microphone angular positions were measured relative to the engine inlet center line.

Ground tests with the treated flight nacelles were conducted for two main reasons: (1) to determine if the noise suppression was as predicted from earlier boilerplate tests, as a prior step to flight testing, and (2) to establish the similarity of noise reduction characteristics between the four flight nacelles.

GROUND TEST RESULTS

Noise spectra measured in the test stand 110^{o} from the inlet axis are shown in figure 3. The variation in SPL for the four treated nacelles, as shown by the shaded area, is approximately 4 decibels, except in the 500-hertz band because of ground reflection

effects. Comparison of the treated nacelles with the previously tested boilerplate and existing nacelles indicated that adequate fan noise reduction has been achieved to meet the program goal.

Prior to conducting the flight test of the treated nacelles, flyover noise levels were estimated from ground test results by using the procedure summarized in figure 4. This method converts ground test data measured at a constant radius on a polar array of microphones around an engine test stand to flyover noise at a required altitude; thus, it provides preliminary information for treated nacelle in-flight noise characteristics.

Test-stand data are corrected for ground reflection effects, temperature, and humidity to standard day conditions. (See ref. 2.) The polar measurements are extrapolated to linear conditions taking into account the inverse square law and atmospheric absorption. Perceived noise levels are calculated for the required altitude for each angular position measured on the ground. (See ref. 3.) By superimposing an airplane velocity on the results, PNL time histories and maximum PNL's are predicted.

The estimated maximum PNL's obtained from test-stand data using this method are shown in figure 5 for an altitude of 400 feet. The estimated noise reduction obtained by the treated-nacelle airplane at the landing approach power setting is shown to be 15 PNdB. Evaluation of these results with flight test data will be made after discussion of the actual flight test results.

ACOUSTIC FLIGHT TEST RANGE

Flight tests were conducted with a 707-320B experimental airplane using the existing nacelles, followed by tests with the acoustically treated nacelles. These tests were conducted over the acoustic test range shown schematically in figure 6. The test range consisted of 20 microphone stations located as shown to measure noise under the airplane flight path during landings and take-offs, and sideline noise 1500 feet from the center line. The position of the test airplane was monitored continuously by means of a radar tracking station. Weather conditions were monitored on the ground as well as up to flight altitudes by using weather balloons and an instrumented light aircraft at regular intervals during the test period.

Acoustic tests were conducted within the following weather restrictions to minimize effects on the noise measurements:

(a) No rain or other precipitation

(b) Relative humidity between 30 and 90 percent

(c) Wind below 10 kn at 10 m above ground

(d) Ambient temperature below ISA + 15^{o} C

The acoustic results presented herein have been analyzed and corrected to standard weather conditions, chosen for this contract to be 70 percent relative humidity and 59° F.

FLIGHT TEST RESULTS

All the test results for a given flight condition and power setting were plotted versus airplane altitude and averaged by drawing a best-fit curve through all the data points as shown in figure 7. The data scatter shown is typical for all the landing approach and level flyover tests and is considered to be satisfactory for the purpose of obtaining reliable average noise levels.

LANDING APPROACH NOISE

The landing approach noise levels measured 1 nautical mile from threshold are shown in figure 8 for both existing and treated airplanes. The noise reduction achieved at this point was 15.5 EPNdB. The equivalent noise reduction on the PNL scale was 16 PNdB. The way this noise reduction has been achieved is shown in detail in figure 9. The difference in the maximum noise spectra between the two airplanes represents the noise reduction. Practically all of the noise reduction is due to the elimination of the fan whine at the higher frequencies. The small reduction shown at the jet noise frequencies is mainly due to the change in directivity of the treated nacelle jet noise because of the coplanar jet nozzles and contributes very little to the over-all EPNL reduction.

Reduction in landing approach noise in the vicinity of an airport is shown in the form of ground noise contours for treated nacelles in figure 10. The land area exposed to noise levels of 100 EPNdB or higher for the treated-nacelle airplane, as shown by the contours in this figure, is only 15 percent of that for the existing airplane.

TAKE-OFF NOISE

Although the primary effort in this program was directed toward reducing landing approach noise, it was found that the reduction of fan noise at take-off power settings reduced the total take-off noise by measurable amounts. The noise reduction achieved under the flight path, 3.5 nautical miles from brake release, was 3 EPNdB, as shown in figure 11. These results have taken into account a climb performance loss for the treated-nacelle airplane of 125 feet at the 3.5-nautical-mile point; this is equivalent to approximately 1 EPNdB loss in noise reduction. The equivalent ground noise contours are shown in figure 12 for a nominal 260 000-pound-gross-weight airplane having a typical range of 2500 nautical miles. The difference in gross weight of 3140 pounds between the airplanes with the treated and existing nacelles has negligible effect on the ground

noise contours shown. It is estimated that the land area exposed to noise levels of 100 EPNdB or higher has been reduced by 55 percent for the treated-nacelle airplane.

Similarly, for take-offs with power cutback initiated just prior to the 3.5-nautical-mile point, it was found that the noise had been reduced by 5.5 EPNdB, as shown in figure 13. The corresponding ground noise contours for a 260 000-pound-gross-weight airplane (fig. 14) show that the land area exposed to noise levels of 100 EPNdB or higher has been reduced by approximately 50 percent for the treated-nacelle airplane.

The results of sideline noise measurements taken 1500 feet from the flight path are shown in figure 15. It was found that sideline noise during take-off was reduced by about 3.5 EPNdB for the airplane with treated nacelles and that the maximum sideline noise levels occurred when the airplanes were at a height of 1000 feet during climbout.

COMPARISON OF ESTIMATED FLIGHT TEST RESULTS

Finally, the flyover noise estimation method was evaluated by comparing the results with flight test data in figure 16. It was found that for this particular airplane configuration and for constant altitude flyovers, the noise levels could be estimated with reasonable accuracy from test-stand data taken during ground run-ups.

CONCLUSIONS

The results of the flight test program on the acoustically treated nacelle show that landing approach noise at the 1-nautical-mile point has been reduced by 15.5 EPNdB. On the equivalent PNL scale, the original contract target noise reduction of 15 PNdB was exceeded by 1 PNdB.

The treated nacelles also showed a noise reduction of 3 EPNdB during take-off and 5.5 EPNdB during take-off with power cutback.

It has been shown that for the engines and airplane configuration used in this contract, test-stand data properly taken and corrected provide reasonably accurate predictions of flyover noise.

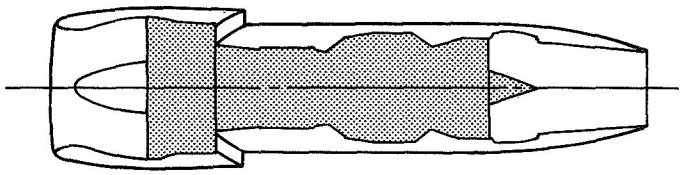
REFERENCES

1. Anon.: Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft. NASA SP-189, 1968.

2. Anon.: Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity for Use in Evaluating Aircraft Flyover Noise. ARP 866, Soc. Automot. Eng., Aug. 31, 1964.

3. Anon.: Definitions and Procedures for Computing the Perceived Noise Level of Aircraft Noise. ARP 865, Soc. Automot. Eng., Oct. 15, 1964.

EXISTING



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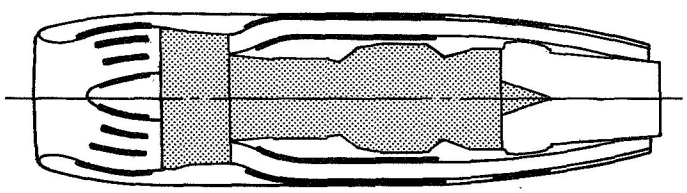
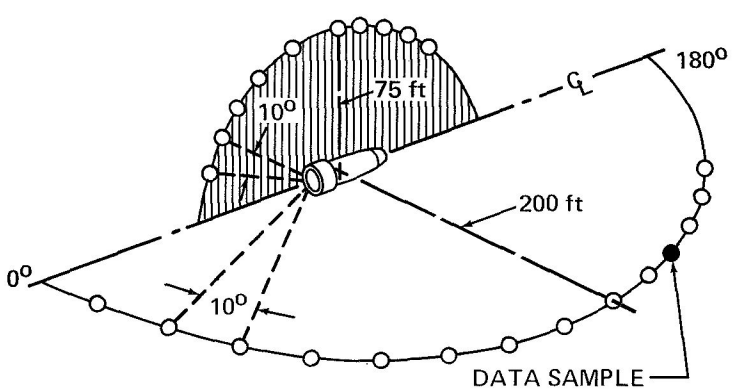


Figure 1

FAR-FIELD MICROPHONES



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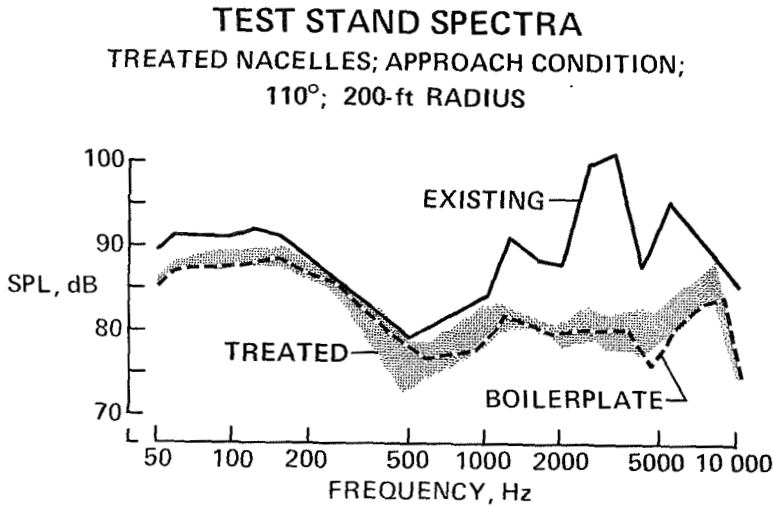

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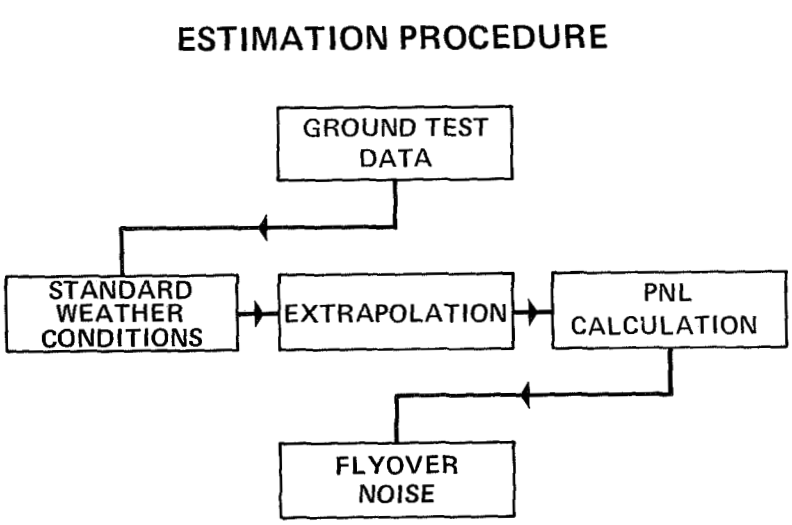

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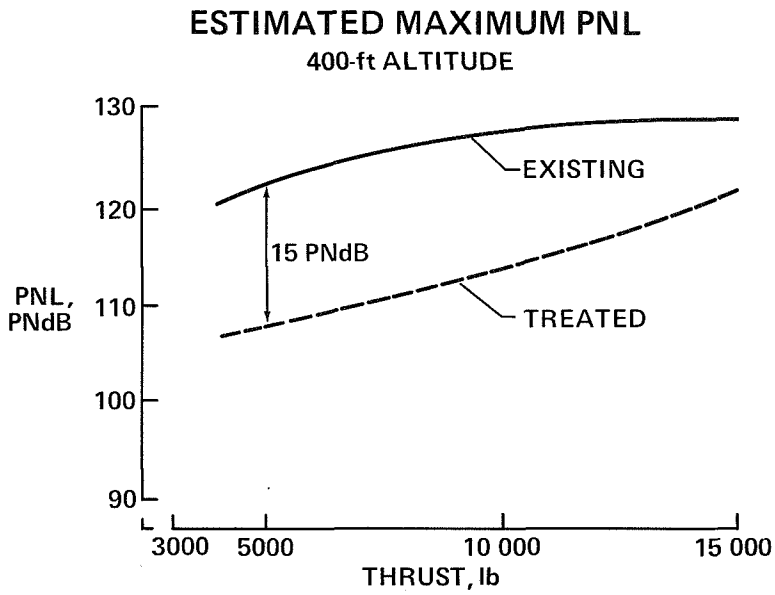

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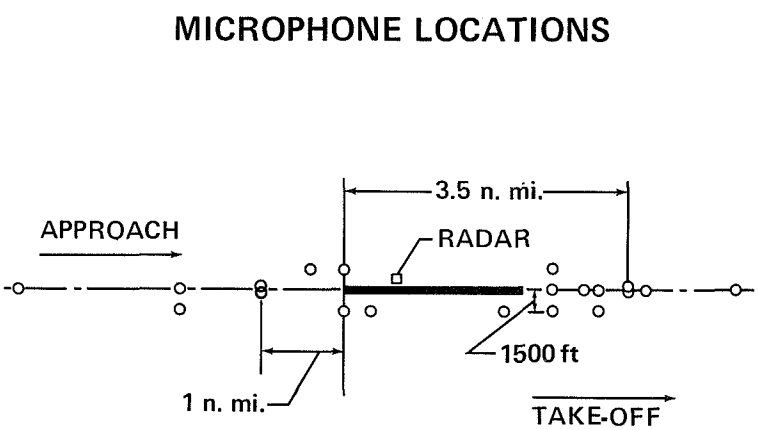

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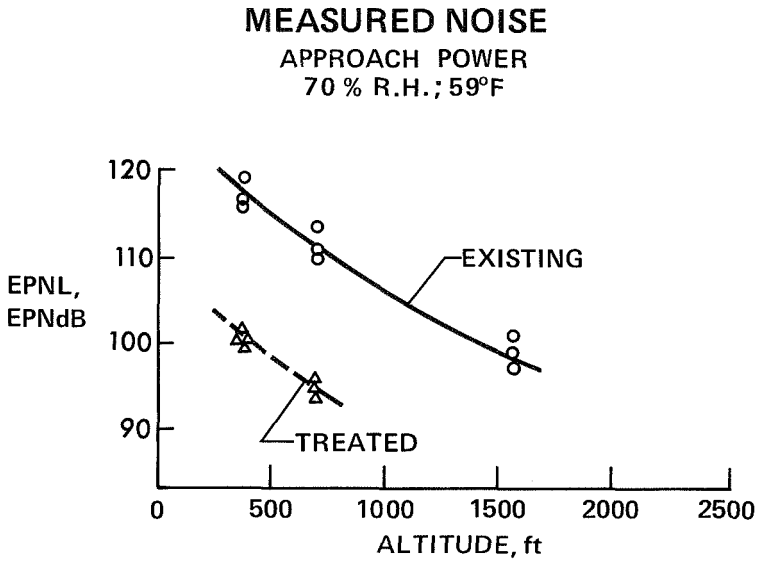

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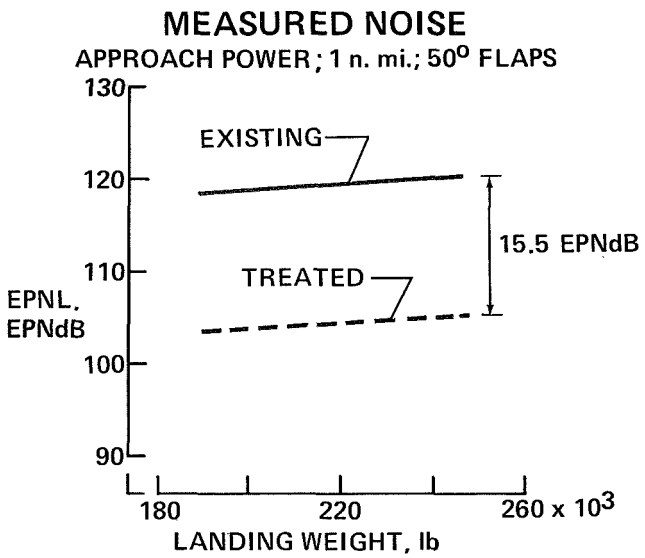

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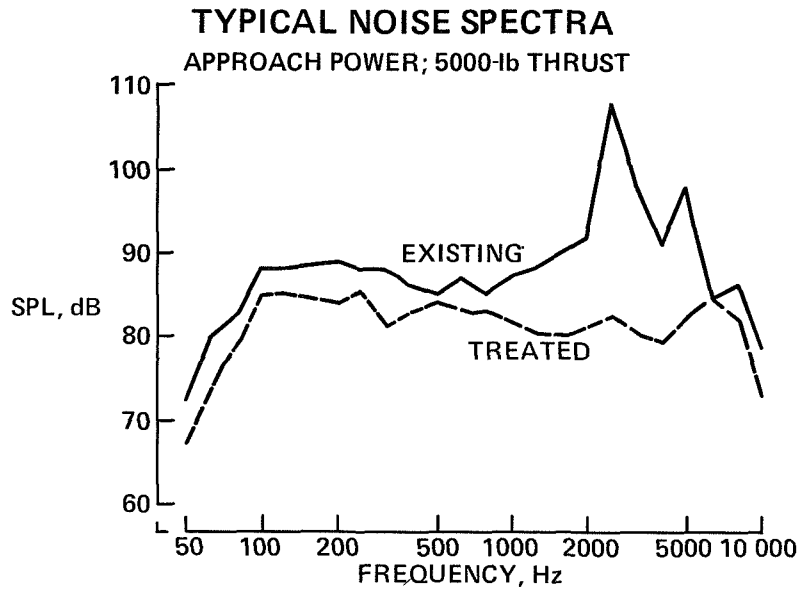

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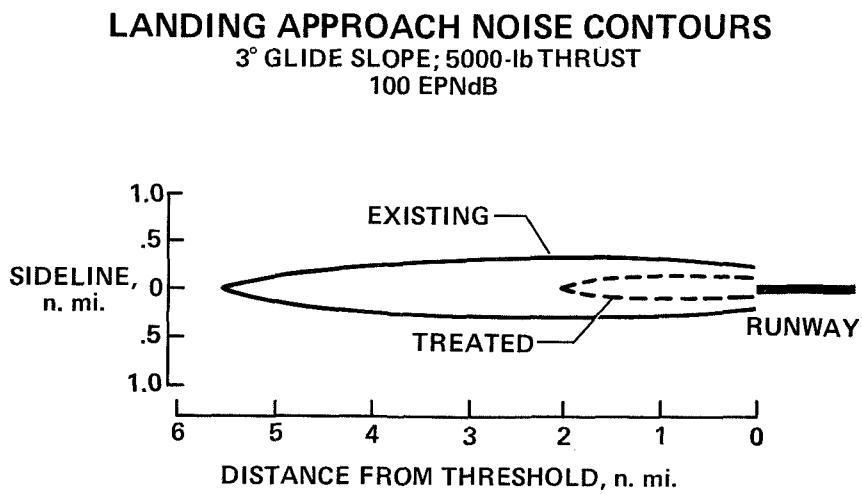

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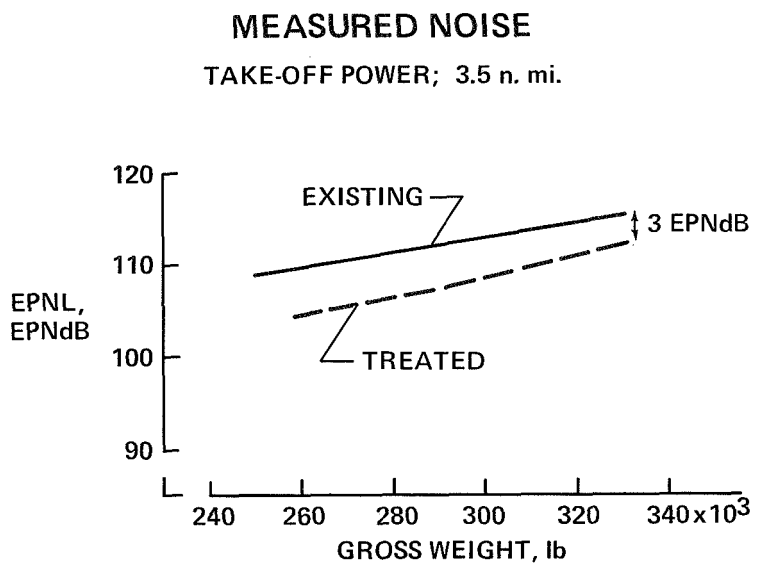


Figure 11

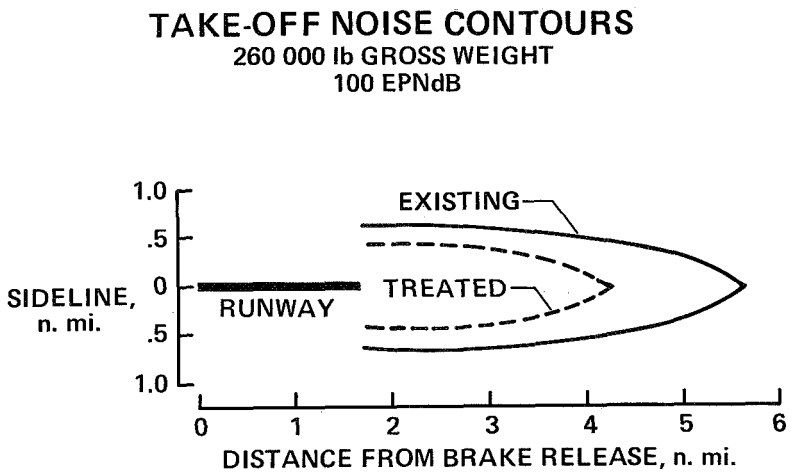


Figure 12

MEASURED NOISE

CUTBACK POWER; 6% CLIMB GRADIENT; 3.5 n. mi.

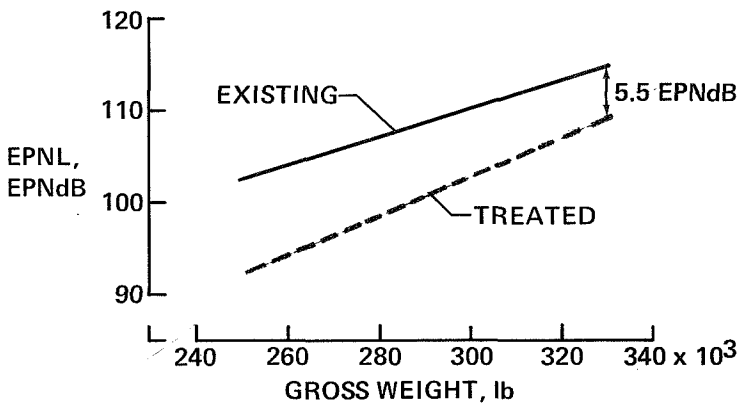
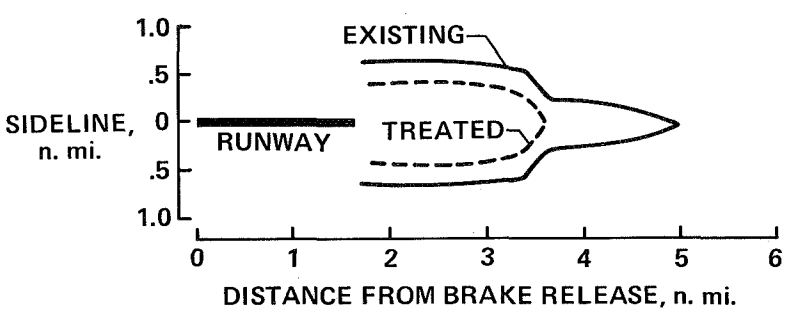


Figure 13

TAKE-OFF NOISE CONTOURS

260 000 lb GROSS WEIGHT; POWER CUTBACK AT 3.5 n. mi.; 100 EPNdB



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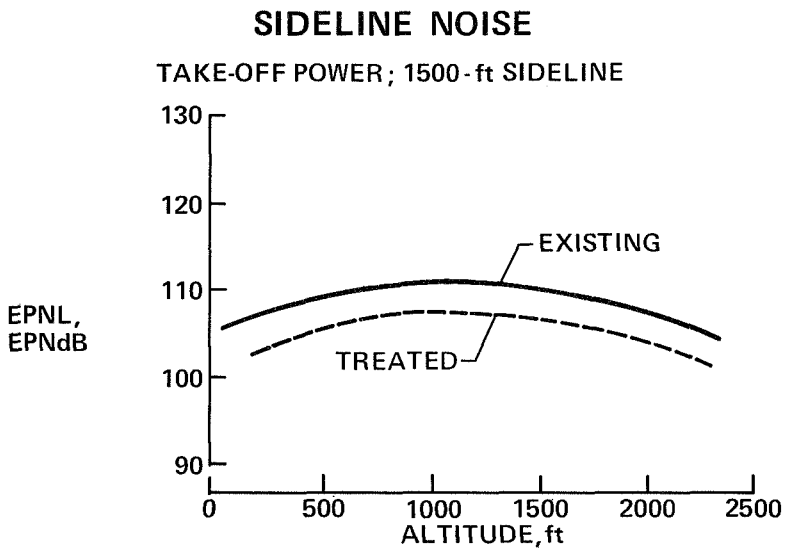

Figure 15

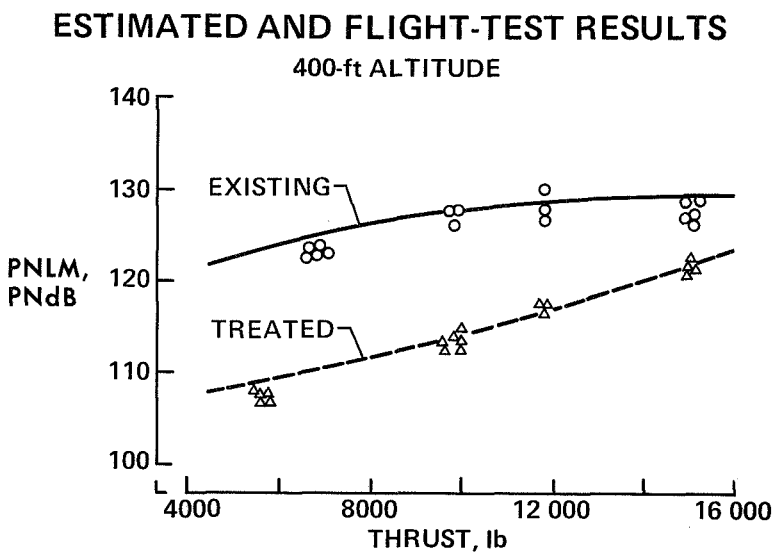

Figure 16